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Methods for Estimating Environmental Effects and Constraints on NextGen

High Density Case Study

S. Augustine, C. Ermatinger, M. Graham, and T. Thompson
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1.0 Overview.....	1
2.0 Top-level Metrics.....	2
3.0 ACES Data Extraction and Preparation.....	3
4.0 Augmentation of Terminal-area Data.....	7
5.0 Population Data.....	15
6.0 Fleet Evolution.....	16
7.0 Operational and Fleet Technology Changes.....	19
8.0 Noise Computation	21
9.0 Fuel-efficiency and Emissions Computation	25
10.0 Constraint Calculation for Noise	28
11.0 Constraint Calculation for Fuel Efficiency	30
12.0 Combining Noise and Fuel-efficiency Constraints.....	32
13.0 Data Review Processes	34
14.0 High Density Case Study Results	34
15.0 Summary and Next Steps.....	43

1.0 Overview

This document provides a summary of the current methods developed by Metron Aviation for the estimate of environmental effects and constraints on the Next Generation Air Transportation System (NextGen). This body of work incorporates many, but not all, of the key elements necessary to achieve such an estimate. The elements addressed are as listed in the Table of Contents above, and each section below contains the background and motivation for the technical elements of the work, a description of the methods used, and possible next steps in each area.

This document is meant to support technical review of current methods, and to engender, in written form, a continuing dialogue concerning goals, requirements, assumptions, and techniques in this area. The current methods described in this document were selected in an attempt to provide a good balance between accuracy and fairly rapid turn around times to best advance Joint Planning and Development Office (JPDO) System Modeling and Analysis Division (SMAD) objectives while also supporting the needs of the JPDO Environmental Working Group (EWG).

In particular this document describes methods applied to support the High Density (HD) Case Study performed during the spring of 2008. A reference day (in 2006) is modeled to describe current system capabilities while the future demand is applied to multiple alternatives to analyze system performance. The major variables in the alternatives are operational/procedural capabilities for airport and en route airspace capacity, operational/procedural capabilities in the terminal area airspace design, and improvements to airframe equipage. For example the High Density (HD) Case study analysis performed during the spring of 2008 used the following three alternatives:

- 2025 Baseline alternative is a “no action” alternative that describes how the system will perform if no improvements are made and demand continues to grow.
- 2025 Fix (NextGen) alternative attempts to overcome operational constraints by delivering solutions which address the problem root causes or mission need drivers. The alternative integrates Operational Improvements (OIs) that will improve system performance in High Density areas of the National Air Space (NAS).
- 2025 Bypass alternative avoids the challenge posed by the root causes, in favor of using tested capabilities to address a variation of the problem, essentially modifying how the existing system is used if no improvements are made.

In modeling each alternative in the HD Case for the environmental effects associated with aviation, flights originating or destined to 164 airports were considered. The airports fall into three categories:

- 34 Continental United States (CONUS) Operational Evolution Partnership (OEP) Airports
- 65 Additional CONUS Airports considered Top Performers due to the number of operations supported
- 65 Additional CONUS Bypass Reliever Airports (83 airports in total were considered for the Bypass scenario 18 of which are from the above list of “Top Performers”)

The effects on the environment are captured or described in two fundamental ways. Indirectly via the operational simulations that capture NextGen improvements for the system and in particular the enroute airspace. And directly by the environmental approach which provides fleet evolution and higher fidelity terminal area trajectories. By combining these two sources we are able to compute the potential environmental changes related to NextGen.

2.0 Top-level Metrics

1. Background

Discussions have occurred between SMAD and the EWG, and the stated targets were applied as environmental constraints:

- Noise – Reduce the number of persons exposed to 65 dB Day-Night Level (DNL) by 4% per year (compounded) relative to a reference year.
- Fuel-efficiency – Improve the average fuel efficiency by 1% per year (compounded) relative to a reference year. Note that fuel efficiency for this analysis is defined as fuel burned divided by distance flown.

2. Method

The top-level metrics described above are currently stated in the FAA's Flight Plan¹, were adapted to the timelines consistent with SMAD analyses, and were presented at both SMAD meetings and with EWG staff. Until official JPDO metrics are defined, these metrics will be used to estimate changes to the environment. These metrics were calculated by the methods described in Sections 8 and 9 below. It should also be noted that these results were provided to the FAA's Aviation Environmental Portfolio Management Tool (APMT) team to estimate the environmental cost implications of implementing any of the future scenarios. Their approach and results are not described in this document.

3. Possible Next Steps

- Top-level review of metrics and goals/targets;
- Extension to other metrics, possibly a payload based fuel metric;
- An analysis of sensitivities of method assumptions in relation to changes in the metrics.

3.0 ACES Data Extraction and Preparation

1. Background

LMINET² and ACES (Airspace Concept Evaluation System)³ have been chosen by the SMAD as the primary operational models to evaluate the NextGen capabilities. LMINET is a queuing network model of the NAS that provides an analytical solution to estimating delays at airports and enroute sectors. ACES provides a fast-time physics-based simulation and modeling capability for performing NAS-wide trade-off analysis. In order to couple NextGen characteristics and behaviors as simulated by the operational

¹ FAA Flight Plan performance reports are available at http://www.faa.gov/about/plans_reports/Performance/

² Dou Long, David Lee, Jesse Johnson, Eric Gaier, Peter Kostiuik, "Modeling Air Traffic Management Technologies With a Queuing Network Model of the National Airspace System", January 1, 1999.

³ ACES Concept Evaluation System – NASA Virtual Airspace Modeling and Simulation Project - <http://www.vams.arc.nasa.gov/activities/aces.html>

models to environmental modeling, ACES simulation results were selected as a fundamental input for the environmental model.

Currently both LMINET and ACES are used as preprocessing or simulation steps for generating the final ACES data used by the environmental model. High level steps in the process are:

- 1) Demand Set Generation – Prior analysis was dependent on a tool named AvDemand to develop demand sets or schedules that corresponds to the target scenarios. (e.g., Hub & Spoke 3X or BizShift 2X). For the subject High Density Case study, schedules were provided by the FAA’s Performance Analysis and Strategy Office and are generated to match specific years and are consistent with the FAA’s Terminal Area Forecast (TAF)⁴.
- 2) Demand Set Trimming – LMI feeds the demand set to LMINET and trims operations to maintain demand capacity ratios.
- 3) ACES Simulation - The trimmed demand set is run through ACES producing a large relational database (MySQL) containing all simulation data.
- 4) Environmental Analysis – Metron Aviation extracts data from the MySQL database to support the environmental modeling. The tables from this MySQL database used for modeling are the *FlightTimeDataMessage* which provides the flight schedules and the *AircraftStateMessage* which provides the flights’ trajectories.

The methods below describe current processes for extracting and extending the ACES trajectories within the terminal area of each airport.

2. Method

Each ACES simulation run generates a large MySQL database that includes various messages generated as a result of the simulation. Prior to noise, fuel, or emissions calculations, portions of this data are extracted from the database and extended to provide more realistic terminal-area traffic behavior. The sections below discuss each of these processes in more detail.

A. Extraction for Noise Calculations

From the MySQL database, the noise modeling is mostly concerned with flight information regarding city-pair, aircraft type, out/off/on/in (OOOI) times, and flight-track geometry. To support the modeling of noise, ACES data must be extended in the following ways:

- Currently ACES has not been configured for detailed terminal area flight track simulation. Since noise analysis typically needs to account for a variety of

⁴ FAA, “Terminal Area Forecast”, <http://aspm.faa.gov/main/taf.asp>.

conditions around an airport, a significant effort is required to develop more detailed trajectory information for noise calculations.

- Additionally, time information captured by ACES is generated in GMT time plus an offset based on the time of the simulation. The DNL noise metric depends on the time of day, since there is a penalty for operations occurring between 10pm and 7am local time. Therefore, in our processing, each operation's on and off times in the ACES output were adjusted to reflect the local time at the airport of origination or destination.

For each ACES simulation run there are three primary phases of work performed in developing the noise-modeling inputs. These phases are:

- 1) Flight data extraction from the ACES MySQL database
- 2) Generation of schedules from the flight data
- 3) Mapping of schedules to terminal area backbones

In the first phase, the ACES data is extracted from the database and manipulated as follows:

- Extract each flight's information from the database in the *FlightTimeDataMessage* table. This data includes: ACES Flight Id, Enhanced Traffic Management System (ETMS) Flight Id, Airline Flight Number, Aircraft Type, Departure Airport, Arrival Airport, and Actual OOOI times.
- Extract the trajectory data for each flight from the database in the *AircraftStateMessage* table. This data includes: Latitude, Longitude, and Altitude and time for each of several nodes describing the trajectory. Since ACES will sometimes generate duplicate nodes to account for enroute delay, all but the last of the duplicate nodes were removed to reduce processing time and preserve node time information. The trajectory data extracted in this way is ultimately not used for actual noise calculations and is instead used to determine a fix location as described in the next section.
- Convert OOOI times for each flight to the local time at origin and destination airports.

The second phase is used to define an event schedule for each airport. The inputs for this step include:

1. The flight and trajectory information from the previous phase
2. Actual fix locations defined from the terminal-area data augmentation method (see next section)
3. A dictionary that maps ACES aircraft types to aircraft categories (J-jet, T-turbo prop, P-prop)

By default, the ACES simulation currently assumes approach and departure fixes to be a set of four locations at 90-degree intervals around the airport. Approach fixes are located at the corners or 45-degrees, 135-degrees, 225-degrees and 305-degrees. Departure fixes are located at 90-degrees, 180-degrees, 270-degrees and 360-degrees. For each airport's

operations, the ACES trajectory data is used to identify the appropriate fix loading. This is done by finding the actual, radar-based arrival or departure fix closest to the simulated ACES arrival or departure fix. From this, an event schedule is defined that includes the following fields:

- City-Pair – used to define a departure weight or stage length
- ACES flight ID – used as an audit trail back to ACES
- Aircraft Type – used during noise, fuel, and emissions calculation
- Aircraft Category – used to match events from the schedule to terminal area trajectories
- Fix – used to match events from the schedule to terminal area trajectories
- Time – used during noise calculation (either the off time or on time, corrected to local time)
- Event Count – used during noise, fuel and emissions calculations

If an operation had arrival and departure airports within the CONUS, separate arrival and departure events were created. In some instances (less than 1%), the ACES trajectories between two TRACONS did not contain enough segments to be used in the analysis and were dropped.

In the third phase, the event schedules defined from the second phase are mapped to the terminal area backbones (see Section 2A) to create weighted backbones (flight tracks with operations) that represent annual conditions. This process uses the aircraft category, time of operation (day/night), and the fix to identify backbones that should carry the operation. Note that each operation is proportionally split across multiple backbones based on the original loading of the backbone from radar data and from the geometric analysis of the percentage that backbone was used during the radar period. For details, please refer to the terminal-area data augmentation section below.

B. Extraction for Fuel and Emissions Calculations

Aircraft trajectories analyzed for fuel burn and emissions of pollutants also are extracted from the post-simulation ACES MySQL databases. These databases contain various tables storing information on the state of aircraft within the simulation at each simulation clock tick. The *FlightTimeDataMessage* table contains one record for each flight that was processed successfully by the ACES system. Key fields extracted from this table are the unique flight identifier, the airline call sign, the aircraft type, departure airport, arrival airport, scheduled and actual OOOI times. The *AircraftStateMessage* table contains records from which the actual flight trajectory is extracted. Key fields extracted from this table are the time, the unique flight identifier, latitude, longitude, altitude, airspeed and thrust. Note that air speed and thrust were not used for calculations but were extracted for future comparisons.

3. Possible Next Steps

- Extend the data extraction method to include flights between airports that had a great circle distance of less than 80 nautical miles, and therefore overlapping TRACON.

- In the current method, VFR flights are modeled for noise, emissions and fuel within the TRACON areas for CONUS OEP airports only. An approach which considers the affects of VFR traffic at non OEP airports should be considered.

4.0 Augmentation of Terminal-area Data

1. Background

Noise analysis is typically performed for an “Average Annual Day”. This represents the spatial variability in traffic patterns throughout the year, and is based on a process of relatively large-scale data sampling and analysis. As mentioned earlier, we seek to achieve cost-effective analysis without sacrificing significant fidelity. In order to capture this level of detail without running an entire year’s worth of flight data through the noise model, the analyst samples radar data and uses it to capture actual flight routes and their dispersion characteristics. This allows the noise model to produce more realistic noise predictions by capturing variations that may be caused by vectoring, changes in runway use or configurations, or other things that produce variability within the terminal area.

The method below describes the process that was used to identify terminal-area traffic patterns for the airports included in the national analysis. Ultimately the process created a large number of flight-route data structures referred to as backbones. The backbones capture information related to operation (arrival or departure), location (fix, airport configuration and runway), and frequency of use (by time and aircraft category). In addition, each such data structure contains information on the spatial dispersion of routes associated with each backbone. This data was later used in conjunction with ACES data preparation method (see previous section) to generate the inputs for the noise model.

2. Method

A. Extensions for Noise Calculations

The first step in our process was to determine the scope or boundaries of the analysis. In the operational simulation using ACES and LMINET, SMAD is using operations for the entire CONUS to compute various metrics with regard to delay and capacity. However, the noise analysis requires significantly more detail, and for this effort was limited to the 34 OEP airports within the CONUS with noise being modeled within 20 nautical miles (nmi) of each airport center. Together these areas cover 43,000 square miles and include a population of roughly 88 million people, based on the 2000 census.

Second, a representative data sample was identified and used to generate the backbones that would ultimately be used as input to the noise model. Because the operational data modeled by ACES was characterized as a “good” weather day in the NAS, the assumption was made that the radar data should also represent a good-weather period. Use of a good-weather period also seems appropriate since there is some expectation that future NextGen capabilities will push the Instrument Meteorological

Conditions (IMC) capacity restrictions to Visual Meteorological Conditions (VMC) levels. Using the period of September 2004 through September 2005 as a basis, Aviation System Performance Metrics (ASPM) and Ground Delay Programs (GDP) data for the primary airports within the area were reviewed, and we identified April 2005, as a period when good weather occurred for the CONUS. The source of data for this 30-day sample was extracted from the ATA-Lab Offload archive which provides detailed terminal data for all modeled airports.

The 30-day radar data sample was assumed to represent appropriate traffic variability under good weather conditions. From this data we derived time of day usage, fix loadings, runway use, and primary airport configurations.

Metron Aviation's ADT (Airspace Design Tool)⁵ was utilized for the detailed analysis of the radar track data for all modeled airports. The data were separated first by airport, then by operation type (arrival, departure), and then further divided by runway. The tracks were then grouped using unique characteristics such as departure headings, arrival intersections, and altitude. Key arrival and departure fixes were also used to identify unique traffic flows. Once the traffic flows were identified, a statistically-determined center track (or backbone) was calculated for each group based on track density within each flow. A set of sub-tracks associated with each center track were also defined to depict the observed lateral dispersion of operations within a flight corridor. The width and density of the flow determined the number and orientation of dispersed sub-tracks within a corridor, and the distribution of radar tracks within a corridor determined the percentage use or weighting of each sub-track. Additionally, each backbone's profile was reviewed to identify any deviations from a 3-degree angle of descent or an unrestricted climb. If sufficient deviations were identified, altitude controls recognized by the noise-model state generator were placed on the backbone in order to better emulate the performance and flight profiles. Finally, the operations from the ACES simulation were transferred to the resulting backbones and were used in the event-weighting process.

Figures 1-4 below present an example of the methodology applied to identify and generate arrival backbones. A portion of the traffic at ORD is shown, and each figure shows a further refinement in the analysis that resulted in the backbones and associated sub-tracks.

⁵ Metron Aviation Inc, Airspace Design Tool, http://www.metronaviation.com/airspace_design.php.

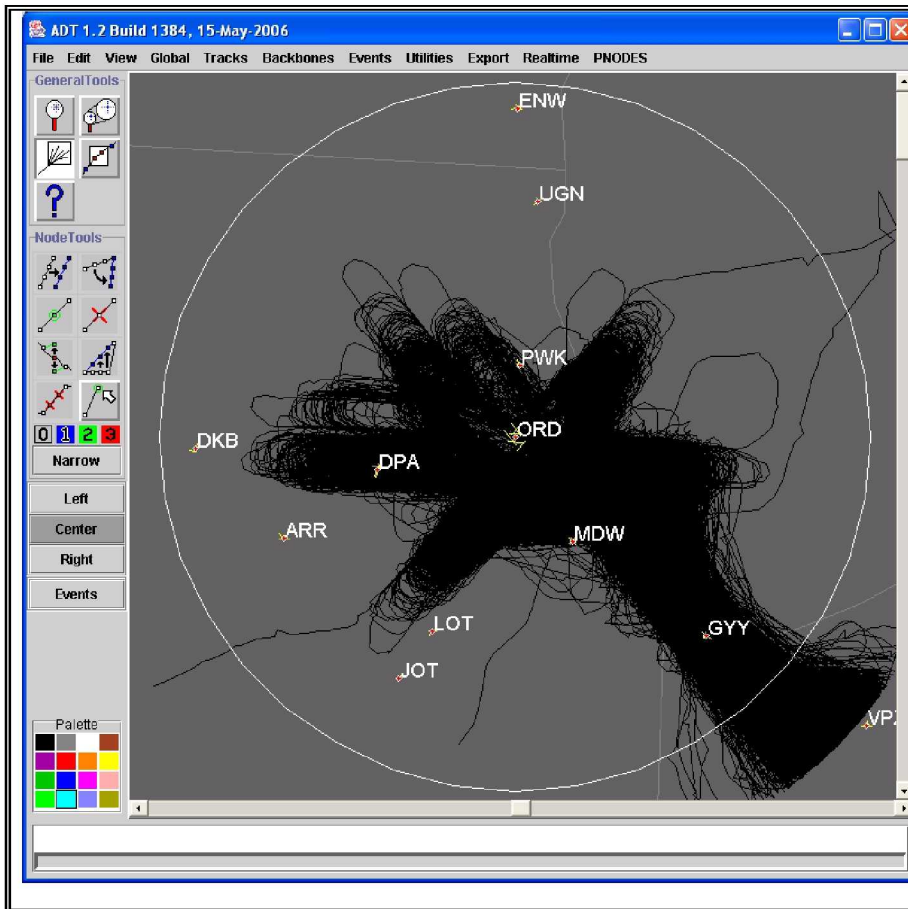


Figure 1: Radar data for ORD arrivals from the southeast (black)

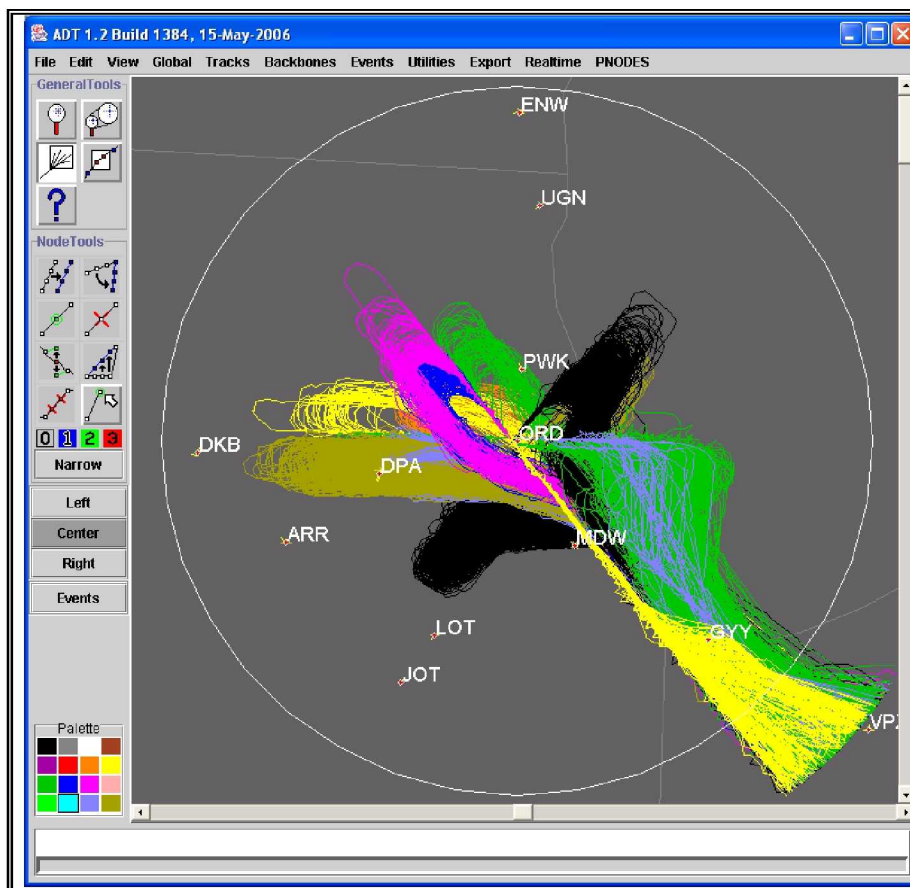


Figure 2: Radar data for ORD arrivals from the southeast grouped by runway and track geometry after spatial analysis using ADT. A small number of tracks judged to be outliers have been removed in this process.

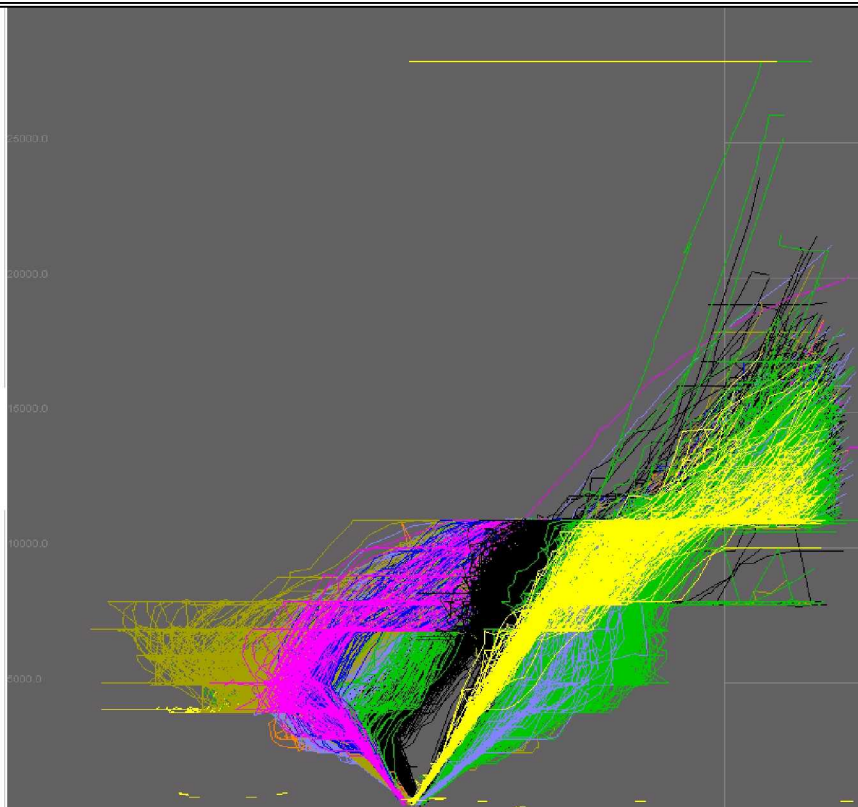


Figure 3: Profile view of radar data for ORD arrivals from the southeast grouped by runway and track geometry.

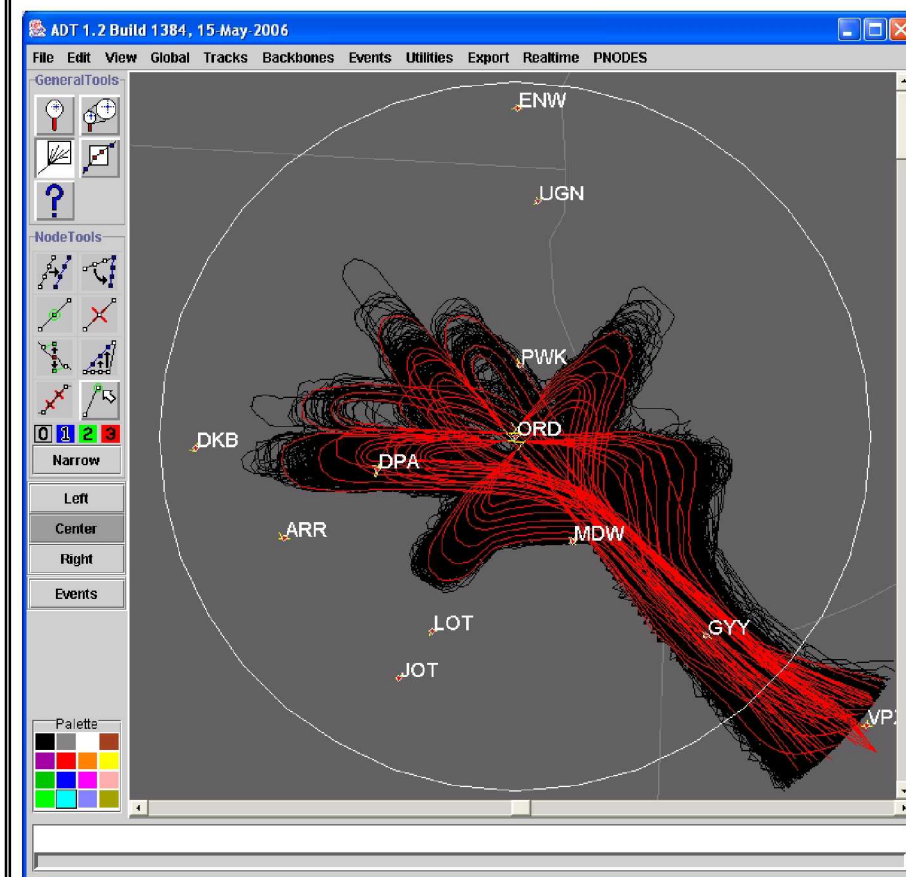


Figure 4: Overlay of the backbones and sub-tracks resulting from Figure 2 onto the data from Figure 1. The net result is a reasonable representation of spatial variability in the radar sample, but in a form that can be coupled with the ACES simulation results.

This process was applied to each of the 34 airports. Noise input files were defined by airport/operation and loaded into NIRS for modeling. For more information regarding the NIRS modeling please refer to the section describing the noise computation itself.

B. Extensions for Fuel and Emissions Calculations

As noted in the above discussion, terminal-area modeling of trajectories for noise metrics is very important. Likewise, to be consistent, for the 34 CONUS OEP airports the same trajectories generated for the noise calculations were used for fuel and emissions calculations. However, for the remaining modeled airports, a less detailed approach was used for the following reasons:

- Detailed terminal-area analysis is time consuming, and has thus far only been completed at 34 airports;
- Differences in the total-flight fuel efficiency due to averaging over different terminal-area trajectories to the same runway for each flight were expected to be small;

Hence, for the fuel-efficiency and emissions calculations, a fairly simplistic approach was taken to generate reasonable extensions from/to the arrival/departure fixes. Following are the steps taken:

1. Since ACES places the metering fixes at 40 nautical miles from the airport, the ACES portion of the trajectory is truncated at 40 nmi from the airport.
2. For each airport of interest, a default configuration consisting of one runway for arrivals and one runway for departures was specified and subsequently used during the construction of extensions at that airport.
3. For an arrival, a reasonably realistic path is constructed from the last ACES-defined point (the truncation point) to the arrival runway. The path geometry assumes a standard arrival pattern (downwind, base, final) and features 3 degree/second turns. Additionally, the entry point into the arrival path is determined by the location of the ACES arrival fix.
4. For a departure, a reasonably realistic path is constructed from the departure runway to the first ACES-defined point (the truncation point). The path geometry assumes an initial straight out path, then smooth (3 deg/sec) turns to connect to the ACES departure fix.

Figures 5 & 6 illustrate the algorithm as it applies to arrivals and departures. **Figures 7 & 8** below present the results of applying the method to ORD arrivals. Note that even though ORD is an OEP airport, it is used here so that a direct comparison can be made with the noise extensions described in subsection A above.

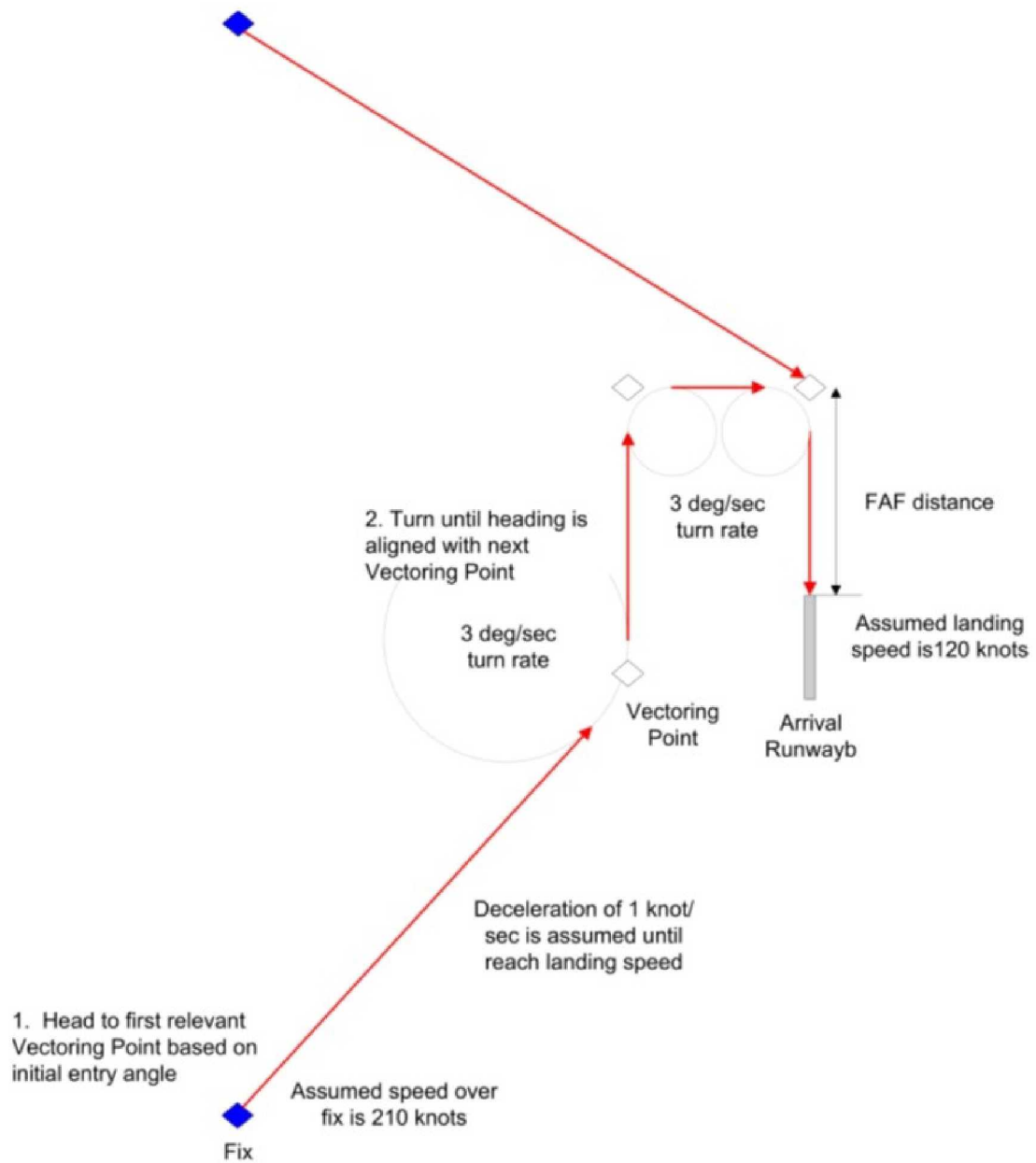


Figure 5: Arrival Extensions

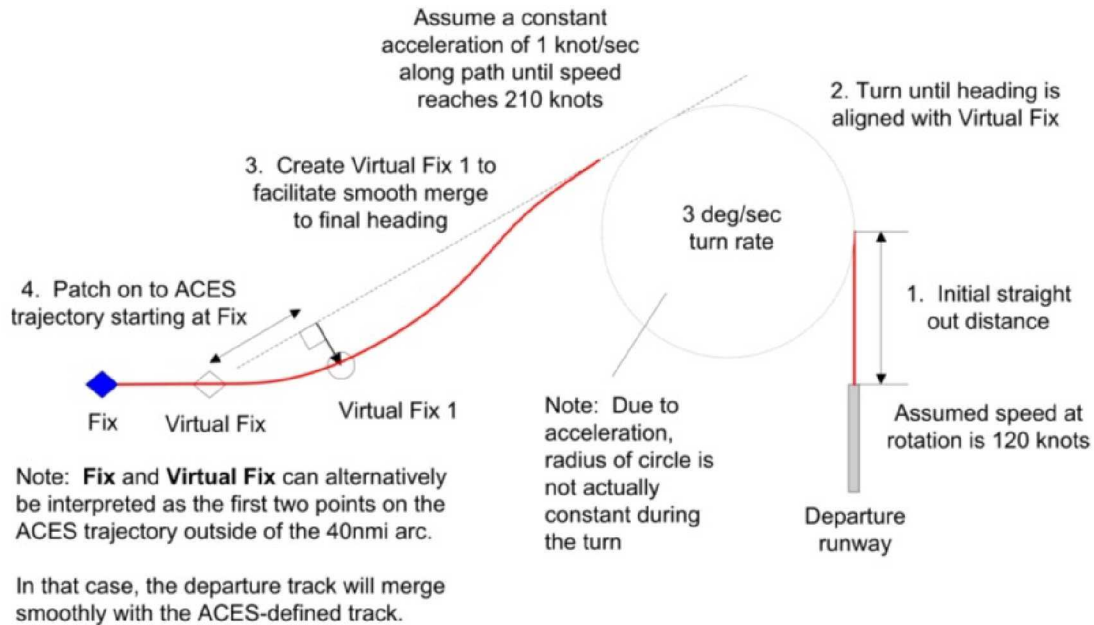


Figure 6: Departure Extensions

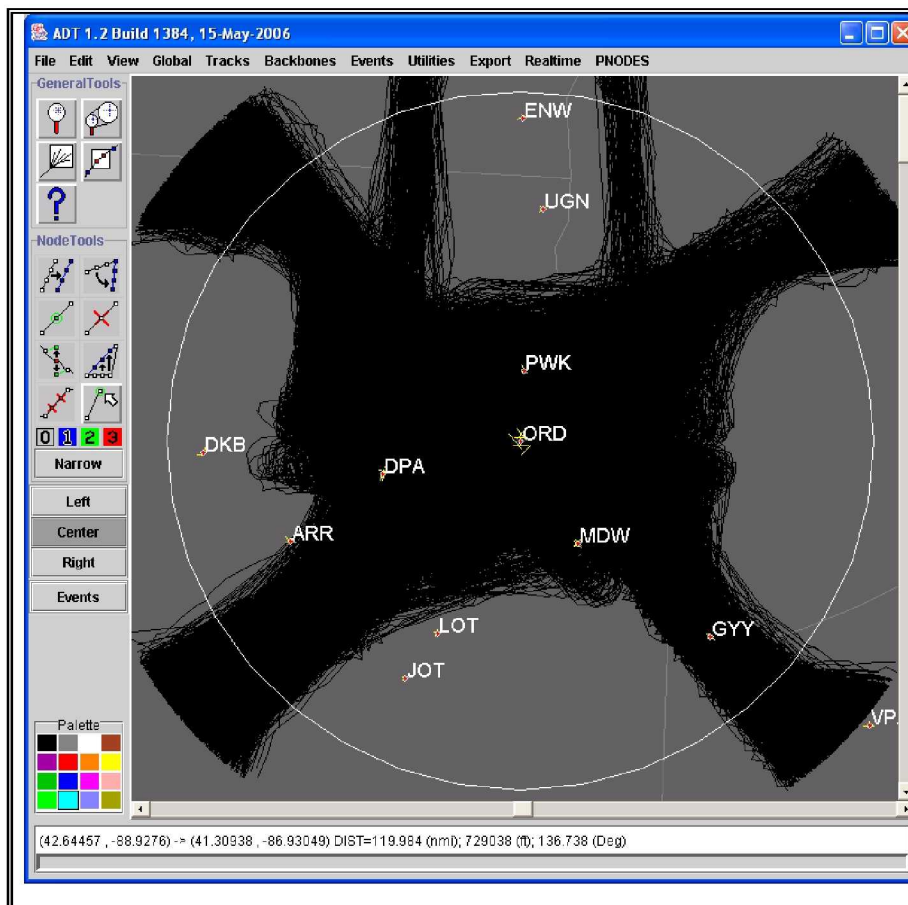


Figure 7: Radar data for ORD arrivals (black) Note that the four arrival corner posts are similar to ACES assumptions, but this is not always the case.

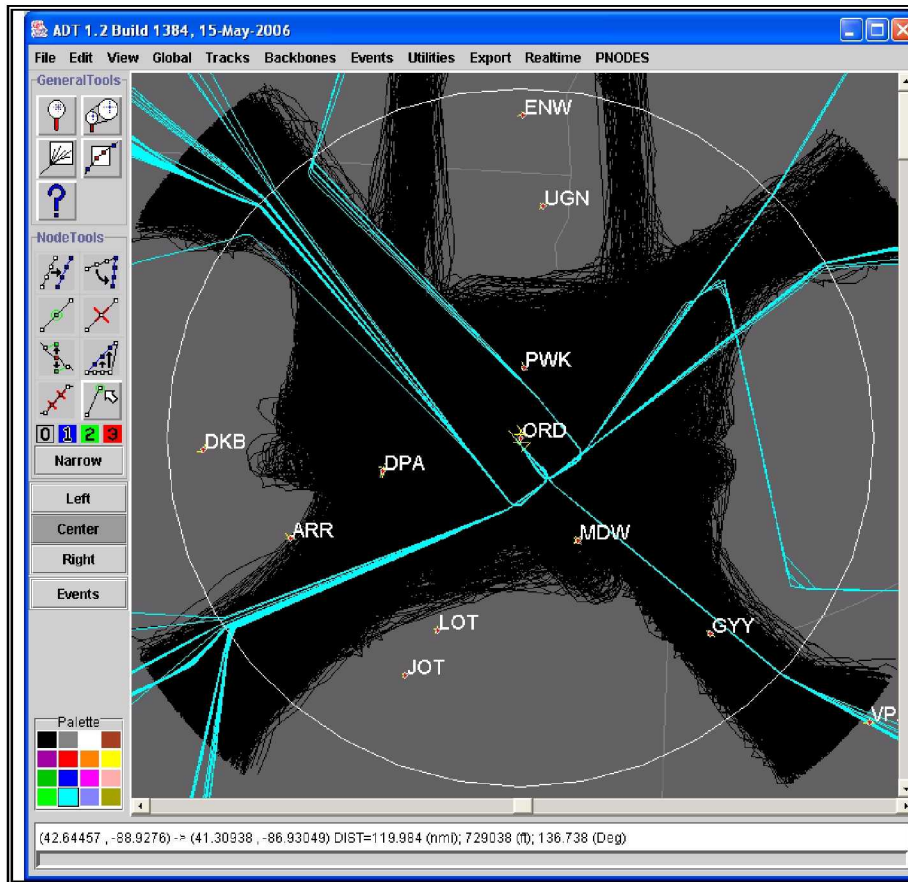


Figure 8: Overlay of the algorithmically generated terminal area extensions (cyan) over radar data (black) for fuel calculations.

3. Possible Next Steps

- Identify additional airports where higher fidelity modeling may be required.
- Perform a sensitivity analysis for fuel and emissions to verify assumptions related to the use of simplified terminal area extensions versus higher fidelity routes should be conducted.
- Perform a sensitivity analysis to determine whether additional radar data should be used to account for seasonal and other variations in traffic patterns.

5.0 Population Data

1. Background

Population distribution is a key input for noise modeling using metrics associated with population counts at various levels of noise exposure. The current analysis evaluates noise conditions for specific locations on the ground based on population centroids (centers of census blocks) throughout the entire study area. Census blocks are the smallest geographic unit for which the Census Bureau tabulates data, and are generally bounded by streets, legal boundaries, and other features. The noise exposure at the centroid location is taken to apply to all population residing in the census block. Note that census blocks vary in shape and centroid location, therefore the actual number of

people impacted can differ from the total population represented by a single census block because noise levels can vary throughout a census block.

2. Method

For this project, the most recent U.S. Census (year 2000) was the primary source of information. Since the initial noise metric uses the number of people exposed to 65 dB DNL, only those centroids within a 20-nmi radius of each airport were used for noise calculation. This results in approximately 88 million people distributed over approximately 1 million centroids.

For this analysis it was determined population forecasting was not necessary. However, it should be noted that the 2000 U.S. Census is now eight years old and may not be an adequate reference point for future runs. In some environmental-analysis projects, population projections are obtained from a commercial source that provides projections for a broader area than the census block. Following the acquisition of this data, additional in-depth review of land-use policies in each locale and identification of residential and non-residential areas is done, and then the projections are extrapolated from the broader areas down to the census blocks. For the purposes of SMAD analysis, a slightly simpler approach would probably be necessary to accommodate the size and scope of the study area.

3. Possible Next Steps

- Perform a sensitivity analysis to determine the appropriateness of using census locations versus a more sophisticated land use analysis.
- Develop or acquire appropriate future population data sets.

6.0 Fleet Evolution

1. Background

An evolving picture of fleet mix is more correctly described as *fleet evolution*, to convey the fact that forecasts of the U.S. and global future fleet are influenced by a number of factors, many of which have a time-dependent component. Point-in-time fleet mix is one of the characteristics which must be accurately captured in projections of NAS demand to realistically model concepts dependent on the composition of the fleet.

Several aspects of NextGen concepts are significantly affected by fleet composition, especially Air Traffic Management (ATM) and environmental impact. For example, ATM is sensitive to such factors as preferred flight levels and routing, while environmental impact is sensitive to aircraft size, engine characteristics, and other factors.

The process by which fleet evolution predictions are made, the factors which influence this process, and the output and format of fleet evolution predictions must be elucidated in order to understand the implications, assumptions, and adaptations that come with incorporating fleet evolution into demand predictions. The approach to fleet evolution for SMAD environmental analysis should incorporate methodologies adopted by both ICAO and the FAA.

2. Methods

For basic modeling of fleet replacement, MITRE's US Air Transport Fleet Forecast 2007 – 2035 was used to evolve the US carrier fleet. This evolution was performed by seat category and percentages of MITRE's forecast by seat category were applied to evolve the fleet. Flights by international carriers and GA operations were not evolved, and cargo and passenger flights were not evolved independently. Figure 9 below provides a high level process description of the method.

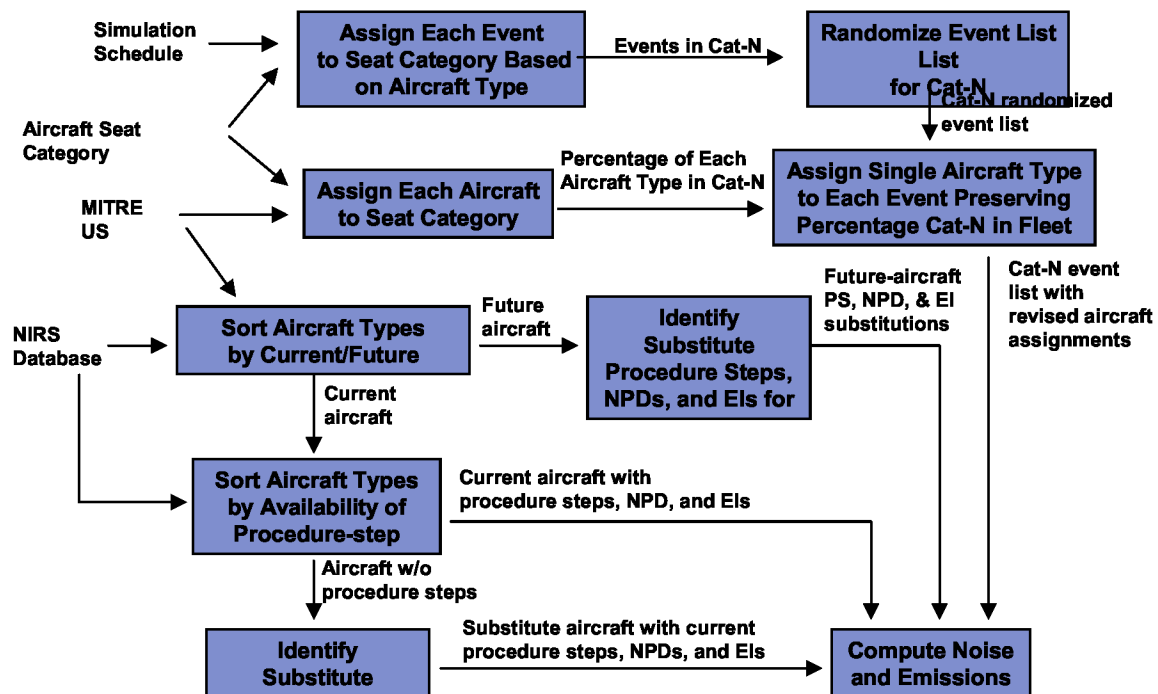


Figure 9: Fleet Evolution Approach

To support the process an aircraft dictionary categorizing each of the aircraft identified in the schedule and MITRE Fleet Forecast was used to assign a corresponding seat class and engine category. The engine categories were jet, turbo-prop and piston while the seat categories were defined as:

- <20 seats
- 20-49 seats
- 50-99 seats

- 100-150 seats
- 151-210 seats
- 211-300 seats
- 301-400 seats
- 401-500 seats
- 501 and greater seats

For each aircraft within a seat class, the MITRE fleet was used to define the proportion that aircraft would be distributed in the proposed schedule. For example, if the MITRE forecast showed 40% of the jets in the 151-210 seat class were Boeing 737-800's then the distribution of aircraft in the schedule for that engine and seat class would be 40% Boeing 737-800. Fleet evolution was performed on the unconstrained schedule.

In addition to mapping aircraft to seat classes and engine categories, assumptions about how new aircraft would be environmentally modeled were also made. In review of the MITRE forecast, there were five new aircraft introduced to the US fleet. In reviewing existing aircraft substitutions and in coordination with the EWG, the following aircraft substitutions were made:

<u>New Aircraft</u>	<u>Substitution</u>
• Airbus A380	Boeing 747-400
• Boeing 747-800	Boeing 747-400
• Boeing 787	Boeing 767-400
• Embraer 175	Gulfstream GV
• Embraer 195	Gulfstream GV

A second form of fleet evolution which includes long range projected aircraft performance improvements was also considered for the most recent analysis. A more detailed discussion of that approach can be found in the section titled Operational and Fleet Technology Changes.

3. Possible Next Steps

- Currently fleet evolution is performed as a pre-process to the demand trimming. If demand trimming is considered to be a market-based trimming then we should consider that fleet evolution should be done after demand trimming and not before.
- In addition to seat class and engine type, fleet evolution should consider user class (Commercial/Cargo/High-end GA).
- Fleet evolution should consider flight itineraries versus independent flights.
- Identify and obtain sources of international fleet forecasts in order to account for international fleet evolution.
- Improve the baseline fleet evolution to include manufacturer projections of "market driven" improvements. (EWG Technology Standing Committee)

- Receive or define aircraft performance for new aircraft entering the fleet from current manufacturers.
- Update the MITRE forecast to the most recent release.

7.0 Operational and Fleet Technology Changes

1. Background

Operational and fleet technology changes defined by the High Density Fix scenario of NextGen encompass a wide domain of improvements that consider airport operations, environmental management, security enhancements, information distribution, air traffic management, improved surveillance and advances in aircraft performance. The improvements can either directly or indirectly change the system's environmental performance. Some of these improvements are modeled upstream from the environmental modeling and then included by incorporating data from the operational models. Other improvements are modeled directly as a part of the environmental analysis. A process of estimating the environmental effects and constraints under assumptions of changes in technology and operational procedures has been addressed in work to date, and will continue to evolve over each iteration of analysis.

A significant challenge involved in the incorporation of operational or technological improvements is an understanding of the implications of the improvement so that it can accurately be modeled. In most cases a review of past research and analysis is performed. In some cases where the research has not been performed, a series of technical reviews and assumptions are made.

2. Method

Along with the operational improvements whose impacts come to us indirectly (principally in terms of number of flights, OOOI times for those flights and en route trajectories), there are three additional improvements modeled specifically for the environment. Two of these, continuous descent arrivals (CDA) and required navigation performance (RNP), deal with the specifics of the terminal area modeling, while the third, fleet technology improvement, deals with both the retirement of older aircraft and the introduction of a quieter, more efficient fleet of aircraft.

Modeling Terminal Area Operational Improvements

As described in earlier sections, the terminal area for this analysis is defined as a 40 nautical mile ring centered at each of the modeled airports. The CONUS OEP airport terminal area procedures for the baseline and future baseline scenarios were derived from a 30 day radar sample while the terminal areas for the remaining modeled airports were generated using an algorithmic approach (see the section titled "Augmentation of Terminal-area Data" for more details).

In an effort to model RNP and CDA-like procedures at the CONUS OEP airports, several assumptions were made. For example, it was assumed that:

- All aircraft originating or destined for these airports were appropriately configured with the proper aircraft navigational equipment, and
- Both RNP and CDA procedures would be overlays of the existing procedures.

This allowed the approach to leverage existing radar data for determining flight paths and lessened the need for airspace redesign, which can be highly controversial and can require a more detailed analysis for each region that is being modeled. These assumptions seem to be consistent with existing practices for defining new RNAV/RNP and CDA procedures today. Note that this approach does not attempt to resolve conflicting procedures that may intersect due to the change in vertical profile caused by implementation of the CDA. Terminal area modeling at the non-OEP airports remains constant for all scenarios.

- RNP levels currently modeled are 0.15 for final approach and 0.5 for the terminal area. Terminal area data for each of the OEP airports is modified to reflect these values prior to environmental modeling. We apply the RNP values to the existing traffic patterns in such a way that the modified traffic flows have the same centerline as current flows.
- CDAs are modeled by extending current NIRS/INM procedure-step data for arrivals to an altitude of 10,000 feet AFE (Above Field Elevation). Descent angles of 2.5 degrees (from 10 Kft to 6 Kft) and 3.0 degrees (from 3 Kft to the runway) are applied to all aircraft.

Current assumptions are 100% equipage and 100% use of RNP routes to all CONUS OEP airports and 100% equipage and 100% use of CDA approaches to CONUS OEP airports in the NextGen future scenarios.

Modeling Fleet Technology Improvements

Technology improvements were included in the High Density Fix scenario by assuming that all aircraft that entered the fleet after 2016 met a goal halfway between FAA's CLEEN program (which also matches the NASA N+1 targets) and NASA N+2 targets.

Improvement Scenario	Introduction Year	EPNL Chapter 4	NO _x CAEP 2 Limit	Fuel Efficiency
Continuous Low Emissions, Energy and Noise (CLEEN)	2016	-32 dB	-63.0%	-25.0%
National Aeronautics Research and Development Plan	2020-2025 (N+2)	-42 dB	-80.0%	-40.0%
Halfway between CLEEN and N+2	2016	-37 dB	-71.5%	-32.5%

Figure 10: NextGen Fleet Technologies

For all seat classes that received new aircraft during the period, a surrogate aircraft was selected and modified to meet the desired environmental performance. Between 2016 and 2025 there were six jet and two turbo prop seat classes that received new aircraft. Note that the A380 introduced a new seat class which had no operations in our future schedules and therefore was mapped to the 401-500 seat class for this analysis.

Surrogate Aircraft	Seat Class	Engine
Canadair RJ-900	050-099	J
Boeing 737-700	100-150	J
Boeing 737-800	151-210	J
Boeing 777-200	211-300	J
Boeing 747-400	401-500	J
Boeing 747-400	>500	J
DeHavilland DASH 8/DHC8-100	020-049	T
Aerospatiale ATR-72	050-099	T

Figure 11: Surrogate Aircraft for Future Fleet Performance

As described in the fleet evolution section, all aircraft in the 2025 forecast, including the new aircraft types created to represent improved environmental performance, were mapped to engine categories and seat classes. Once this was completed the fleet was again distributed to the scheduled operations by proportion and seat class.

3. Possible Next Steps

- Requirements review.
- Extend CDA definition to “top of descent”.
- Refinements to the level of usage for both RNP and CDA procedures. These refinements could include identifying airports and specific procedures at each airport.
- Perform separate analysis to distinguish the effects of operational and technology improvements.
- Perform an analysis to determine what performance and insertion requirements are needed to meet the desired environmental targets.

8.0 Noise Computation

1. Background

The FAA has specified which metrics, such as DNL, should be used for federal aviation noise assessments. DNL is an energy-average noise level over a 24-hour period except that 10 dB is added to those noise events occurring at night (between 10 p.m. and 7 a.m.). This weighting reflects the added intrusiveness of nighttime noise events attributable to the fact that community background noise levels typically decrease by about 10 dB during those nighttime hours. DNL does not represent the sound level heard

at any particular time, but rather represents the total (and partially weighted) sound exposure.

As a result of the DNL metric's high correlation with the degree of community annoyance from aircraft noise, DNL has been formally adopted by most federal agencies for measuring and evaluating aircraft noise for land use planning and noise impact assessment. Federal interagency committees such as the Federal Interagency Committee on Urban Noise (FICUN) and the Federal Interagency Committee on Noise (FICON), which include the EPA, FAA, Department of Defense, Department of Housing and Urban Development (HUD), and Veterans Administration, found DNL to be the best metric for land-use planning.⁶ They also found no new cumulative sound descriptors or metrics of sufficient scientific standing to substitute for DNL. Other cumulative metrics could be used only to supplement, not replace, DNL. Furthermore, FAA Order 1050.1E for environmental studies requires that DNL be used in describing cumulative noise exposure and in identifying aircraft noise/land use compatibility issues.⁷

The FAA has further established that all detailed noise analyses must be performed using the most current version of the FAA's Integrated Noise Model (INM), Heliport Noise Model (HNM), or Noise Integrated Routing System (NIRS)⁸. Additionally the FAA has determined that for air traffic airspace actions where the study area is larger than the immediate vicinity of an airport, incorporates more than one airport, or includes actions above 3,000 feet AGL, noise modeling will be conducted using NIRS. For those types of studies, NIRS will be used to determine noise impacts from the ground to 10,000 feet AFE.⁹ For the reasons described above, NIRS was selected as the appropriate model for analyzing the OEP airports.

Another contributing factor to the current analysis is the increased scope of the number of airports to be considered for noise analysis. With the introduction of the Bypass scenario, where excess capacity is moved from OEP airports to nearby satellite airports, an additional 65 airports were modeled. Given the time and resources required to support modeling at these airports, the FAA screening method or Area Equivalency Method¹⁰ was applied. Unlike the higher fidelity models, the Area Equivalency Method requires only fleet and schedule to estimate the potential exposure to noise. However, the AEM only produces areas exposed to noise and not population exposed, so it is not a suitable tool for the more detailed analysis done at the OEP airports.

The section below describes the method used to compute noise for the national analysis.

⁶ Federal Interagency Committee on Noise (FICON) (1992). "Federal Agency Review of Selected Airport Noise Analysis Issues". Ft. Walton Beach, FL: Spectrum Sciences and Software, Inc.

⁷ FAA, "Draft Environmental Impact Statement - New York/New Jersey/Philadelphia Airspace Redesign", Federal Aviation Administration, December 2005.

⁸ INM, HNM, and NIRS model summaries are available at http://www.faa.gov/about/office_org/headquarters_offices/aep/models/

⁹ FAA Order 1050.1E Environmental Impacts: Policies and Procedures, Department of Transportation, Federal Aviation Administration, June 8 2004.

¹⁰ FAA, "Area Equivalent Method Version 6.0c User's Guide", Office of Environment and Energy, November, 2001. See also "Area Equivalent Method Version 2.0 User's Guide", 1989.

2. Method

Noise Modeling at OEP Airports

The NIRS model requires the following principal inputs to predict noise levels:

- Study Area – includes the study center location, size, elevation at the center, maximum altitude for the study, and average meteorological conditions.
- Population – a set of point locations (latitude/longitude) which describe the population location and density. Typically this data is developed from the Census Bureau. See the section on Population above for more detail.
- Terrain – terrain data extracted from the US Geological Society. This data is used in conjunction with the population locations to determine the actual distance between a flight route and the population.
- Runways – a list of runways and their location information.
- Traffic files – a set of files that define flight operations within the study. These files contain flight track geometry and flight operations (aircraft type, origin, destination, time of day and weighting) on a route-by-route basis.

For the current pass through the noise analysis, the following assumptions were made:

- The study center location was set to the middle of the CONUS. In the version of NIRS that was used, the runway elevations are considered, and the runway elevation is the elevation used for flights using that runway. NIRS does not currently use meteorological data (temperature, barometric pressure) from multiple airports. For this project default meteorological conditions were used for the entire study area
- Detailed study-area terrain data was used for each of the airports to properly account for changes in elevation.
- The NIRS default altitude of 18,000 feet MSL was used as a study ceiling.
- Population was assumed to stay constant (see Section 5 above for discussion), and thus used U.S. Census 2000 levels for all scenarios. Population was also further constrained to only those points within 20nmi of a study airport. Although the current metric for noise is the number of people exposed to 65 DNL or greater, it was anticipated that exposures at lower levels may be of interest, and the 20-nmi radius allows for closure of all contours 55 dB DNL and above.
- Only today's runways were modeled. There were no future runways added to the model for any of the 34 airports, but, if available, additional data could be incorporated on future runways. ORD, where a massive runway construction and realignment is planned, is a prime example.
- For the High Definition case study, traffic files were modified to support future enhancements to the terminal area. For a more detailed discussion refer to the section titled "Operational and Technology Changes".
- Fleet mix for future scenarios was incorporated into the analysis. Additionally, future technologies that improved noise and fuel efficiency were also considered.

For a more detailed discussion please refer to the Fleet Evolution & Operational and Technology Changes sections of this document.

- Time of day was extracted from the ACES runs and used to define day/night split.
- Runway use and airport configurations were assumed to be accurately captured from the radar sample collected. For those airports where data was not good enough to define the routes, the analyst used his/her professional judgment.
- Traffic files were divided by airport and operation.

For each ACES run in the regional analysis there were 68 NIRS traffic files produced (34 airports * 2 operation types). For each of the traffic files the following steps were executed:

- 1) Import the traffic file into NIRS
- 2) Use the NIRS Flight Segment Generator (FSG) to apply SAE 1845 equations and the NIRS aircraft performance data to simulate aircraft performance to meet the trajectories defined within the traffic file. For more detail about FSG, please refer to the NIRS User Guide¹¹.
- 3) Compute noise using the results of FSG for points within a 20nmi radius of the airport servicing the traffic in each file. For example, if the traffic file was for ORD departures, we computed noise for all population locations within a 20nmi radius of ORD.
- 4) If the 20nmi rings intersect between multiple airports the population locations were combined and used for noise computations. For example, ORD and MDW are within 40nmi of each other and therefore the population surrounding MDW may be affected by operations from ORD. In order to consider the cumulative effect of noise, the locations for both MDW and ORD were combined into a single population file for both airports. For the 34 OEP airports, there exist 4 regions that combine multiple airport locations into a single population file for all airports; EWR-JFK-LGA, FLL-MIA, BWI-DCA-IAD, and MDW-ORD.

After noise was computed for all flights and airports associated with the given noise metric, the resulting noise exposure was aggregated for each population centroid, and the number of people exposed above 65 dB DNL was calculated.

As discussed in the metrics section, the initial noise goal was stated as a 1% decrease in the number of people exposed to 65 DNL or greater over each year. That goal has since been changed to 4% per year. The reference year of 2006 was used to compute current conditions, and multiple future scenarios describing operations in 2025 were also modeled.

Noise Modeling at Bypass Airports

The Area Equivalent Method (AEM) model as developed by the FAA is distributed as an Excel workbook and requires the following inputs:

¹¹ FAA, "NIRS 6.1 User Guide", Air Traffic Organization, System Operations Service Unit, System Operations Airspace and AIM Office, Environmental Programs Group, AJR-34, January 2006.

- Aircraft
- Daytime and nighttime counts of Landing and Takeoff Cycles (LTO)

Additionally AEM is prepackaged with the supported INM aircraft types. Because we introduced new aircraft to the analysis and for convenience, AEM was redeveloped to accept an input that included:

- Aircraft
- Operation (Arrival/Departure)
- Actual operation time (as modeled via ACES)

Data were extracted and localized from the ACES database for each of the 83 Bypass satellite airports. These data were then processed in AEM and areas were computed for each airport. Areas for each airport were added for each scenario to show potential cumulative changes in area exposed to new noise levels. The FAA has established screening criteria for reviewing AEM results and determining whether additional modeling is required. If the area exposed to greater than 65 dB DNL grows by more than 17%, the FAA assumes that there is potential for significant change and proceeds to either develop a more detailed environmental assessment or reconsiders the change.

3. Possible Next Steps

- Consider inclusion of meteorological conditions at each airport;
- Consider breaking the traffic files into finer resolution to allow for mixing of scenario input. For example if the Baseline and a Future scenario are divided by aircraft category as well as operation, it would be possible to mix technology improvements from an aircraft category. Additionally traffic files could be defined by runway, configuration, by aircraft category (type or weight or seat count) or even time of day (day/night). This could also allow for more flexibility with performing the constraints analysis and trimming/scaling a particular category of operations or aircraft differently from another.
- Perform a review of runway improvements considered for the CONUS OEP airports and develop an approach for considering these improvements in the environmental modeling. Examples of this would include runway extensions, new runways or a reconfiguration of the airport's layout.
- Enhance the use of the area equivalency method to produce an estimate of a metric consistent with NIRS (i.e. population exposed to significant noise).
- The current FAA Flight Plan compares current noise levels to a three year average (2000-2002), should we consider developing a baseline scenario consistent with this timeframe?

9.0 Fuel-efficiency and Emissions Computation

1. Background

We seek a means by which to calculate fuel efficiency on a flight-by-flight basis, consistent with the top-level metric. Fuel efficiency is currently expressed in units of kilograms of fuel per kilometer flown, and is calculated over all phases of flight. Other definitions of the distance portion of this metric are possible, such as using the inter-airport distance in lieu of the trajectory distance. Seat capacities are currently not used in the fleet fuel-efficiency metric. Additional extensions to address other characteristics (carrier specificity, cargo vs. passenger type, etc.) are possible, given sufficient data.

2. Method

Fuel calculations for each flight are carried out using a combination of fuel-flow values from the Emissions & Dispersion Modeling System (EDMS 4.3)¹² below 3000 feet AGL and the Base of Aircraft Data (BADA)¹³ fuel flow values above 3000 feet AGL. The basic fuel burn equation is given by

$$\text{Fuel Burned} = t_m * R_m$$

where:

t_m is the time in minutes for a mode of operation m

R_m is the rate of fuel flow in kg/minute for a mode of operation m

BADA fuel flow is expressed in kg/sec for the aircraft during the phases of climb, cruise, and descent at different altitudes. EDMS fuel flow is expressed in kg/sec for each engine of the aircraft during the phases of taxi/idle, takeoff (to 1000 feet AGL), climb (1000 feet AGL to 3000 feet AGL), and approach (3000 feet AGL to touchdown). Note that the EDMS rate is therefore additionally multiplied by the number of engines attributed to the airframe.

Emissions calculations utilize the value of fuel burned in each phase to compute the mass of pollutants – CO, HC, NO_x, and SO_x – concurrently generated. The basic emissions equation is given by

$$\text{Pollutant Mass} = F_m * EI_m$$

where:

F_m is the mass in kg of fuel burned in mode m

EI_m is the emissions index in grams/kg for pollutant generated in mode m

The following are the processing steps for fuel burn, emissions inventory, and flight ground track distance computation:

¹² FAA, “Emission & Dispersion Modeling System Version 4.3 User's Guide”, Office of Environment and Energy, August, 2005.

¹³ Eurocontrol, Base of Aircraft Data Version 3.6, September 2004,
http://www.eurocontrol.int/eec/public/standard_page/ACE_bada_documents_36.html.

- a. The Taxi In/Out time is taken from the ACES actual OOOI data and EDMS taxi/idle fuel flow values are used to derive the fuel burn during the taxi phase. EDMS taxi/idle emission factors are used to compute the pollutant totals emitted during surface movement. Note that since aircraft ground movement is not modeled, zero distance is attributed to this phase of operation.
- b. The airborne aircraft trajectory is broken into several phases for fuel burn and emissions computation:
 - EDMS takeoff fuel flow and emission factors from takeoff to 1000 feet AGL.
 - EDMS climb fuel flow and emission factors from 1000 feet AGL to 3000 feet AGL.
 - EDMS approach fuel flow and emission factors from 3000 feet AGL to touchdown
 - BADA fuel flow is used for all portions of the trajectory above 3000 feet AGL. In order to apply BADA fuel-flow factors, each distinct segment was classified as either a climb segment, a cruise segment, or a descent segment. However, for all flight segments in BADA space (namely above 3000 feet AGL) the EDMS approach emission factors alone were used to compute pollutants emitted.
- c. The trajectory's ground-track distance is computed in nautical miles from the beginning of takeoff roll to the end of touchdown on a segment-by-segment basis. Though we compute the trip distance from the actual trajectory, the distance could in fact be computed as a great-circle distance between the departure airport and the arrival airport. This would make the trip distance more of an economic trip unit rather than a trip distance based on actual trajectories and their variances (such as holding or weather avoidance).
- d. Most international flights in the ACES data (and possibly some others) do not contain both the departure and arrival portions of the trajectory. In these cases (approximately 5-10 percent of the flights), we use only that portion of the trajectory available for fuel burn and emissions computations.
- e. Terminal area trajectories are developed from two sources. If the terminal area is for an OEP airport, the higher fidelity trajectories used for noise calculations are used for fuel and emissions calculations. For non-OEP airports the algorithmic trajectories discussed in the section "Augmentation of Terminal-area Data" are used.

The fleet average of the above flight fuel efficiencies is calculated as the arithmetic mean across all flights. The fleet average for the baseline data set is the basis for calculating the future fuel-efficiency goal.

3. Possible Next Steps

- Compute the FAA's Payload-based Fuel Efficiency metric in addition to the current fuel efficiency metric.
- Provide supplement fuel-efficiency metrics for comparison and to consider sensitivities to those metrics already defined.

10.0 Constraint Calculation for Noise

1. Background

One of the assignments of the SMAD is to estimate what portion of future “unconstrained demand” will not be achievable under specific perceived future NextGen scenarios. To support these efforts we seek a tractable method of estimating what fraction of the modeled fleet operations would need to be shed to meet a noise goal expressed in terms of total population exposed above a threshold specified in dB DNL, a standard noise metric. The method used here finds a fractional scaling coefficient that can be applied to each flight based on its contribution to the noise energy reaching population on the ground. This scaling coefficient can then be used to calculate the fraction of the total flights shed to meet a specified noise goal.

This scaling can be applied either before or after similar flight shedding applied by others to meet capacity constraints. To date we have applied this after capacity-based shedding.

The method discussed here estimates this fraction without addressing issues associated with specifically determining which flights might be shed in a real-world effort to meet the noise goal, since this would require addressing complex policy issues of fairness, economic impact, etc. This initial method is one way of estimating the fraction based on simple assumptions, and it is envisioned that we can build upon this approach to gradually address more complex issues.

This method is an extension of standard impact-aggregation techniques already in wide use in current environmental analyses. These standard techniques combine noise energy from different patterns of traffic in order to create aggregate exposures at each population location that reflect various factors, such as airport configuration, seasonal variations, operational procedures, etc. It should be noted that these patterns of traffic can include, in addition to track geometry, such things as aircraft type, time of day, origin/destination, etc.

Because the standard technique is often used to create average annual representations of these many factors for use in impact analyses, it will be called here the *standard annualization* technique. The basis for the standard annualization technique, and our extensions thereof, will be described below.

2. Method

The standard annualization technique is based upon the following chain of calculations:

- a. Single Event Level (SEL) is determined at each population centroid for each segment of each trajectory modeled. Each appropriate SEL value is calculated from an FAA database of noise-power-distance surfaces specific to

different aircraft/engine types. SEL is a time-integrated expression of sound energy in which each acoustic event is normalized to a duration of one second.

- b. Day Night Average Sound Level (DNL) is calculated from SEL as follows:

$$D_{\text{tot}} (\text{location } j) = 10 \log \left\{ (1/T) \sum_i (d_i + 10n_i) 10^{(\text{SELi})/10} \right\}, \quad (1)$$

where the summation is over each event (i), and D_{tot} is the total DNL at a given population location (j) due to all flights (i). In this equation, d_i is the number of daytime events of a specific airframe/engine type on the same five dimensional trajectory (x, y, z, speed, thrust), while n_i is the number of night events. Night is defined in this metric as the period from 2200 to 0659 local time. T is equal to the number of seconds in a day, 86,400.

- c. The events inside the summation above can be grouped in any convenient way. In a simple annualization case for a single airport, each group represents trajectories associated with a different operating configuration of a given airport, and all flights using that airport are included in each group. Then the equation is re-written with annualization factors representing the fraction of the time each configuration is in use throughout the year, as follows:

$$D_{\text{tot}} = 10 \log \left\{ (1/T) \left[a_1 \sum_{1i} (d_i + 10n_i) 10^{(\text{SELi})/10} + a_2 \sum_{2i} (d_i + 10n_i) 10^{(\text{SELi})/10} + a_3 \sum_{3i} (d_i + 10n_i) 10^{(\text{SELi})/10} + \dots \right] \right\}, \quad (2)$$

with the sum of the a_i being 1.0.

- d. Using the basic definition of DNL, we can also write, for each group above:

$$D_1 = 10 \log \left\{ (1/T) \sum_{1i} (d_i + 10n_i) 10^{(\text{SELi})/10} \right\}, \quad (3)$$

or, in simplified notation in which the summation represents the entire expression, including the $(d_i + 10n_i) 10^{(\text{SELi})/10}$:

$$D_1 = 10 \log \left\{ (1/T) \sum_{1i} \right\}. \quad (4)$$

- e. From (2) and (4), we achieve the operating version of the standard annualization equation:

$$D_{\text{tot}} (\text{location } j) = 10 \log \left\{ a_1 10^{(D1)/10} + a_2 10^{(D2)/10} + a_3 10^{(D3)/10} + \dots \right\} \quad (5)$$

Equation (5) is implemented as a part of our in-house toolkit, and, once one has computed the values of all the D_i , one is able to determine the total DNL at any location with simple exponentiation and logarithmic operations.

Given the above capability, and given a noise-impact goal that is expressed in terms of total population above a specified DNL threshold, we have the means to set the coefficients in (5), compute the resulting DNL values at all population locations, and compute the resulting total population above the threshold. In the flight-shedding method, we repeat this process until the desired goal is achieved, and we use the resulting coefficients to determine the fractional numbers of flights shed in achieving the goal.

The first step in the process is to calculate the number of people exposed to 65 DNL or greater in the baseline year. Then one of several quantitative goals (e.g., 1% reduction per year) is then applied to this baseline number to identify the target total number of people exposed to 65 DNL or greater. Then the shedding method is applied to reduce flights until this goal is met. The shedding is ordinarily applied uniformly across all types of traffic and across all airports.

An optional part of this method involves differential shedding of day and night operations. Because noise exposure is heavily affected by nighttime operations and the capacity-trimming algorithm was assumed to give preference to nighttime operations the noise-goal shedding can, if desired, reduce nighttime operations more severely than daytime operations. One side effect of this is that it might impact cargo carriers that tend to use the nighttime hours for transport (there were two cargo carrier airports in the current region). We have explored several different relative day/night scalings, and have used, as a simple assumption for some runs, a fixed rule that reduces nighttime operations twice as much as daytime operations. We then iteratively applied the factors until the goal was met. Although this is a useful starting point, it should be noted that the initial runs ended up with fewer nighttime operations in the future than in the baseline. Further discussion is needed to more completely determine what assumptions should be made with regard to differentiation of day and night shedding. Different day/night ratios could be applied, or more detailed treatment of sub-sets of nighttime traffic might be appropriate (e.g., reduce nighttime heavy operations on specified runways at specified airports). This more-detailed level would require a greater understanding of the land use and existing noise mitigation routes at each airport.

3. Possible Next Steps

- Explore the refinement of scaling assumptions with regard to additional criteria: time of day, aircraft weight class or seat class, etc.

11.0 Constraint Calculation for Fuel Efficiency

1. Background

We seek a tractable method of estimating what fraction of the modeled fleet that would need to be shed to meet a fuel-efficiency goal expressed as a *fleet average* (for example, total fleet fuel divided by total fleet distance flown). This method is extensible to several forms of the fuel-efficiency metric (e.g., fuel per unit of payload distance).

Our method estimates flights shed but does not determine which flights would be shed in real-world efforts to meet a fuel-efficiency goal, since this would require addressing complex policy issues of fairness, economic impact, etc. This method estimates the fraction shed based on simple assumptions, and it is envisioned that we can build upon this approach to gradually address more complex issues.

2. Method

The method developed here has two forms:

- Method F1 (“Share the Pain”) finds a fractional scaling coefficient that can be applied to each flight whose modeled flight fuel efficiency is worse than the desired fleet average. This scaling coefficient can then be used to calculate the total fraction shed to meet the desired fleet average.
- Method F2 (“Worst First”) sheds flights in whole numbers starting with those whose flight efficiencies are worst (i.e., highest amount of fuel per distance traveled or other unit of output). Flights are shed sequentially until the desired fleet average is attained.

Method F1 generally will give a higher estimate for the total flights shed than Method F2, since F1 sheds portions of all flights with efficiencies worse than a certain value, while F2 sheds unitary flights in a worst-first fashion. The principal steps in each method are described below.

Method F1

1. Select a goal for fleet fuel efficiency. For example, a goal might be reduction in a baseline fleet efficiency by 1% per year over a period of N years.
2. Choose a target *flight* fuel efficiency, E, less than the average of the *flight* fuel efficiency for all flights. Divide operations into two groups: those with efficiency above (worse than) E, and those with efficiency below (better than) E.
3. Require average *flight* fuel efficiency of over all flights to be equal to E:

$$E = \text{target average flight fuel efficiency} = (\sum_1 e_i + S \sum_2 e_i) / (N_1 + S*N_2),$$

where

N = total number of flights;
 e_i = individual fuel efficiency of the i th flight;
 N_1 = number of flights with e_i below (better than) E ;
 N_2 = number of flights with e_i above (worse than) E ;
 S = scaling factor;

and the summations \sum_1 and \sum_2 are over the N_1 and N_2 flights, respectively.

4. Calculate fraction of flights shed to meet the average *flight* efficiency goal:

Fraction of flights shed to meet *flight* efficiency goal = $1.0 - (N_1 + S \cdot N_2)/N$.

5. Repeat for several target *flight* efficiency values, and find the fraction of flights shed that gives the desired *fleet* efficiency value of E_{fleet} .

Method F2

1. Select a goal for fleet fuel efficiency. For example, a goal might be reduction in a baseline fleet efficiency by 1% per year over a period of N years.
2. Order all operations in terms of the *flight* fuel efficiency for each flight.
3. Shed whole flights, starting with the worst *flight* fuel efficiency (highest value of fuel per unit output) first.
4. Shed flights until the *fleet* fuel efficiency for the unshed flights is equal to E_{fleet} .

Prior to final fuel-efficiency calculations, fuel and distance values in the input data are reviewed. Outliers are identified and excluded from the final calculation. Typically we have required that distances must be greater than 50km and fuel/distance values must be between 0.5 and 20.0.

3. Possible Next Steps

- Extend this technique to other fuel-efficiency metrics (e.g., fuel per unit payload-distance).
- Review additional metrics that could be considered for flight trimming.

12.0 Combining Noise and Fuel-efficiency Constraints

1. Background

Our overall objective is to bring environmental constraints into a common framework for comparison with capacity constraints. Having generated individual estimates of these constraints for specific noise and fuel-efficiency goals, we seek a means of integrating these two types of environmental constraints into a single environmental constraint.

The technique articulated here does not address relative economic or societal values associated with the noise and fuel-efficiency goals. It takes these goals as given, and merges individual measures of the magnitude of these constraints when each goal is addressed in isolation.

2. Method

If noise and fuel trimming affect exactly the same population of flights, then, after noise and fuel-efficiency shedding have been applied, we have produced a list of all flights processed, with each flight falling into one of the following categories:

- a. Flights affected by the noise goal alone;
- b. Flights affected by the fuel-efficiency goal alone;
- c. Flights affected by both goals; and
- d. Flights affected by neither goal.

In this list, each flight will have two numbers associated with it: a noise scaling and a fuel-efficiency scaling. If either of these numbers is 1.0, then the flight was not affected by the goal associated with that number.

At the moment, computational and data limitations mean that the population of flights being treated are not the same for both noise and fuel. For example, noise trimming may be applied only at airports for which terminal-area trajectories are available, while fuel trimming can be applied to all flights. Additionally, we currently remove some outliers as part of Q/A for fuel-efficiency calculations independently of noise calculations. We are working to remove these differences.

Once the flight populations are aligned, we can combine the noise and fuel-efficiency trimming as follows:

- For each flight, select the lower of the noise or fuel-efficiency scaling numbers (that is, the one that requires more trimming), and calculate the total flights remaining after trimming by summing across all flights using this value.
- The fraction of flights remaining is this number divided by the original number of flights (equivalent to the average of the resulting flight-specific scaling factors).

3. Possible Next Steps

- Requirements review;
- Refinement of the technique to reflect the requirements.

13.0 Data Review Processes

1. Background

Various aspects of the environmental metrics are quite sensitive to the input data for environmental modeling. In order to identify errors and anomalies, we review the input and output data from several perspectives.

2. Methods

Our principal data-review processes are as follows:

- Ratios of arrival and departure operations by airport in each scenario are calculated and reviewed. These should be close to one. Airports reviewed are limited to those having a minimum number of operations (e.g., 50 departures per day).
- Ratios of total operations by airport between each alternative scenario and the baseline scenario are calculated and scatter grams of these ratios are plotted. Across alternative scenarios, for a given airport, it is expected that such ratios should not differ dramatically unless there are features in the alternatives that would explain such differences. Airports reviewed are limited to those having a minimum number of operations (e.g., 50 departures per day).
- A process similar to (the previous bullet) is applied to fuel use for departure and arrival operations at each airport in each scenario.
- Prior to final fuel-efficiency calculations, fuel and distance values in the input data are reviewed. Outliers are identified and excluded from the final calculation. Typically we have required that distances must be greater than 50km and fuel/distance values must be between 0.5 and 20.0.

3. Possible Next Steps

- Create a review process which considers the operations removed by demand or environmental trimming.
 - In regard to demand trimming consider changes to trip distance, network affects and fleet mix.

14.0 High Density Case Study Results

1. Background

The System Modeling and Analysis Division of the JPDO is responsible for the modeling and evaluation of the performance of NextGen in several areas. A key component in the evaluation of NextGen capabilities is how the environment will be

affected. The results generated by the environmental analysis provide the desired metrics to assist in the evaluation and include the following results:

- Noise
 - Population exposed to 65 dB DNL for the CONUS OEP airports (additional levels of exposure are available)
 - Area exposed to 65 dB DNL for the 83 Bypass airports
- Fuel Efficiency & Emissions
 - Fuel Efficiency is computed as fuel burned per unit distance flown for all flights originating or destined for 164 airports.
 - Emissions Inventories for 164 airports have been calculated. Inventories include NO_x, SO_x, HC, and CO produced below 3,000 feet AFE.
 - Fuel and Emissions are also computed for other phases of flight. Flight phases are divided by:
 - Taxi-out
 - Takeoff surface to 1,000 feet
 - Climb from 1,000 feet to 3,000 feet
 - Climb from 3,000 feet to 10,000 feet
 - Enroute from 10,000 feet to 10,000 feet
 - Descent from 10,000 feet to 3,000 feet
 - Descent from 3,000 feet to the surface
 - Taxi-in

	Fuel and Emissions Calculation	Noise Calculations
Airports Modeled with Higher Fidelity Radar Based Terminal Area Inputs	34	34
Airports Modeled with Algorithmically Generated Terminal Area Inputs	130	
Airports Modeled with Scheduled Based Terminal Area Inputs		83
Airports Modeled	164	117

Table 14. 1 Airports Considered by Metric

The subsequent sections will review the results for each of the components over the scenarios analyzed for the High Definition Case Study. As a reminder the scenarios considered were:

- 2025 Baseline alternative is a “no action” alternative that describes how the system will perform if no improvements are made and demand continues to grow.
- 2025 Fix (NextGen) alternative attempts to overcome operational constraints by delivering solutions which address the problem root causes or mission need drivers. The alternative integrates Operational Improvements (OIs) that will improve system performance in High Density areas of the National Air Space (NAS).

- 2025 Bypass alternative avoids the challenge posed by the root causes, in favor of using tested capabilities to address a variation of the problem, essentially modifying how the existing system is used if no improvements are made.

All three future scenarios were compared with a reference day (in 2006) to describe current system capabilities. The major variables in the alternatives are operational/procedural capabilities for airport and en route airspace capacity, operational/procedural capabilities in the terminal area airspace design, and improvements to airframe equipage.

2. Results

The following sections present the results for noise exposure and fuel efficiency as calculated for High Density case study.

2.1.Noise

We have applied the noise modeling and methods discussed previously to four scenarios within the High Density Case Study. In each scenario we computed the population exposed to greater than 65 dB DNL at the CONUS OEP airports (Figure 14.1) and calculated the change in area exposed to greater than 65 dB DNL for the 83 Bypass airports (Figure 14.2).

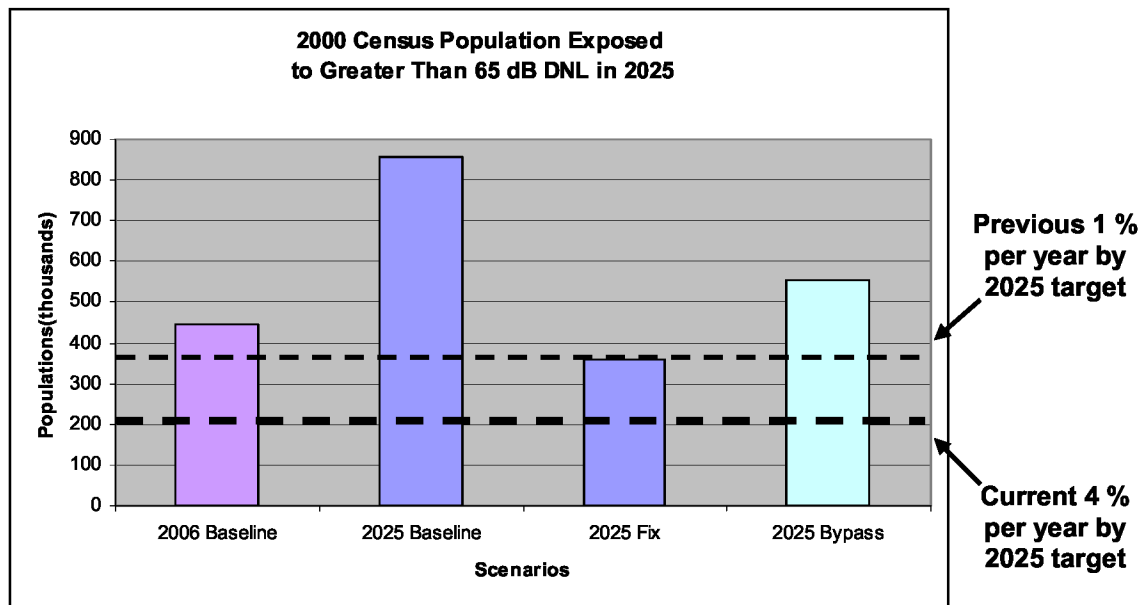


Figure 14.1 Population Exposed to 65 dB DNL by Scenario

In review of the population exposed (Figure 14.1), none of the scenarios performed well enough to meet or exceed the current 4% goal of reducing the number of people exposed

to significant noise on an annual basis. While the fix scenario performed better than any other scenario, even with significant A/C technologies it barely meets the old 1%/yr target and is well above the new target. As suggested previously, a simpler model that computes areas exposed to significant noise levels was used to understand potential noise changes at airports with fewer operations. In Figure 14.2, where cumulative areas exposed to 65 dB DNL are shown, we see a similar trend.

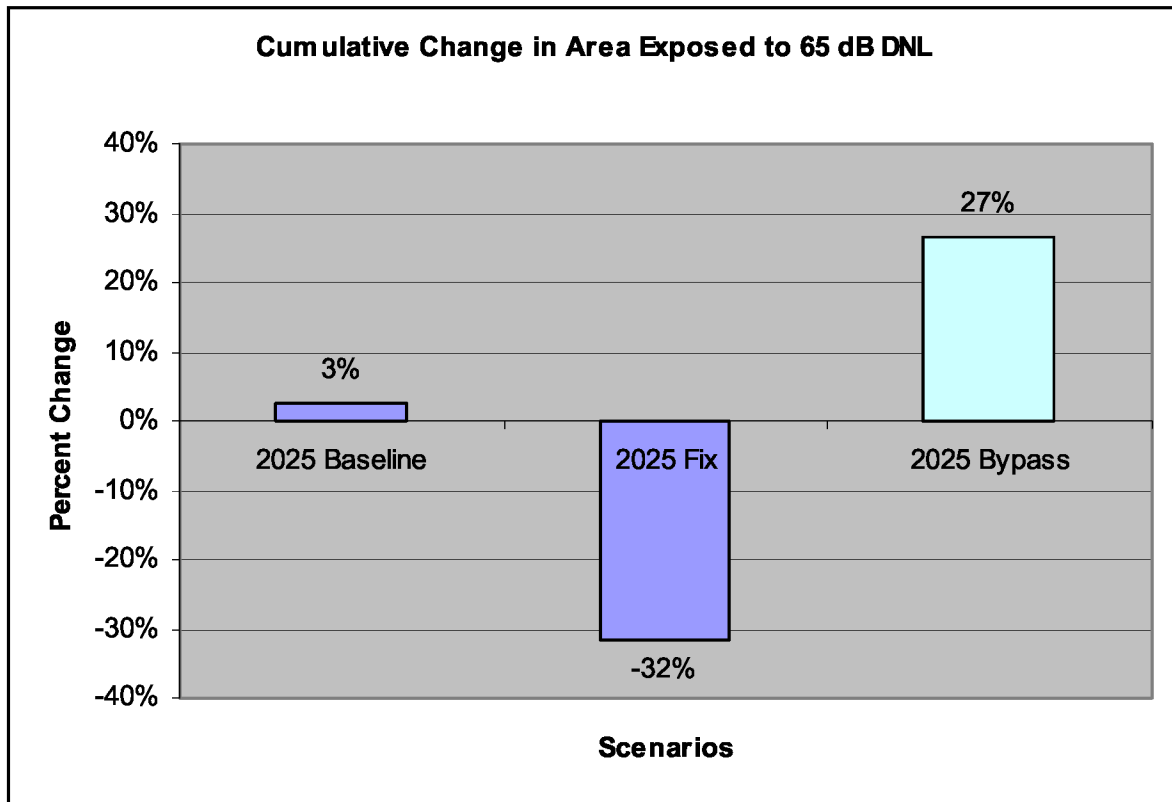


Figure 14.2 Area Exposed to 65 dB DNL by Scenario

Trimming Flight to Meet Noise Goals

We have also applied the noise trimming method described previously to the noise results in an effort to describe the gap between the noise targets and the actual result. By doing this we are able to estimate the number of flights trimmed to meet the goal. The 2006 scenario shows approximately 444 thousand people exposed to at least 65 dB DNL. The desired goal of 4% per year reduction in the number of people exposed would result in a target of 204 thousand people by 2025. Table 14.2 below presents the percentage of flights at OEP airports that would need to be trimmed to meet these goals by 2025.

Scenario	% Trimmed
2025 Baseline	69%
2025 Fix	37%
2025 Bypass	53%

Table 14. 2 Percentage of OEP Operations Trimmed to Meet 2025 NextGen Targets

2.2.Fuel Efficiency

We have applied the fuel-modeling and fuel-efficiency methods discussed above to four data sets from the High-density Case Study. The principal characteristics of these data sets are shown in the table below, along with the modeled fleet fuel efficiency. The fuel efficiency is shown in two forms: (1) using all modeled flights, and (2) using only those flights that have distances greater than 50km and fuel/distance between 0.5 and 20.0 kg/km. Table 14.3 gives the results both before and after this filtering. The 2006 Baseline fleet fuel efficiency of 3.59 kg/km was used as the reference value for calculating improvements (see trimming discussion below). That entry is highlighted in Table 14.3 to clearly point it out.

Table 14. 3 – Fuel-efficiency (FE) Ranges for the HD Scenarios Studied

Scenario	Data Status	Flights	Fleet FE ² (fuel/distance)	Minimum Flight FE ³ (fuel/distance)	Maximum Flight FE ³ (fuel/distance)	Average Flight FE ³ (fuel/distance)
2006 Baseline	Before Q/A	39333	3.57242	0.04610	38.34860	3.27300
	After Q/A ¹	37886	3.59110	0.50010	19.98250	3.30280
2025 Baseline	Before Q/A	56527	3.57822	0.04610	44.94800	3.39966
	After Q/A ¹	54777	3.55989	0.50000	19.96350	3.35595
2025 Bypass	Before Q/A	58096 ⁴	3.36782	0.04610	38.80380	3.19476
	After Q/A ¹	56376 ⁴	3.36508	0.50009	19.99800	3.17542
2025 Fix	Before Q/A	56523	3.12264	0.04610	38.60480	2.95135
	After Q/A ¹	54817	3.11979	0.50011	19.99320	2.93598

¹ Q/A in this context means filtering on the above-stated ranges of distance and fuel/distance values.

² Fleet FE is defined by the total fuel burned divided by total flight distance

³ Average Flight FE is defined by the average of per flight fuel divided by its distance

⁴ ByPass flight counts are higher due to the fact that larger aircraft were split into smaller regional aircraft suitable capable of using secondary (bypass) airports.

Trimming Flights to Meet Fuel-efficiency Goals

We have applied the fuel-efficiency trimming methods discussed above to the same data sets. A range of fuel-efficiency goals has been explored in order to understand the sensitivity of the trimming magnitudes to different goals.

The results are summarized in Figure 14.3 below. The horizontal axis in this figure is the *total* improvement in fleet fuel efficiency relative to the 2006 baseline. The values of total improvement obtained by applying an *annual* goal over a number of years are given in Table 14.4. For a fixed value of total improvement on the x-axis, the vertical spread measures the difference in trimming required to achieve that improvement in different scenarios and using different trimming methods. For a fixed value of trimming on the y-axis, the horizontal spread between points measures the total improvement achievable across scenarios using different trimming methods. Given the number of flights in each scenario, a trimming level of 10% is approximately equal to 5500 flights.

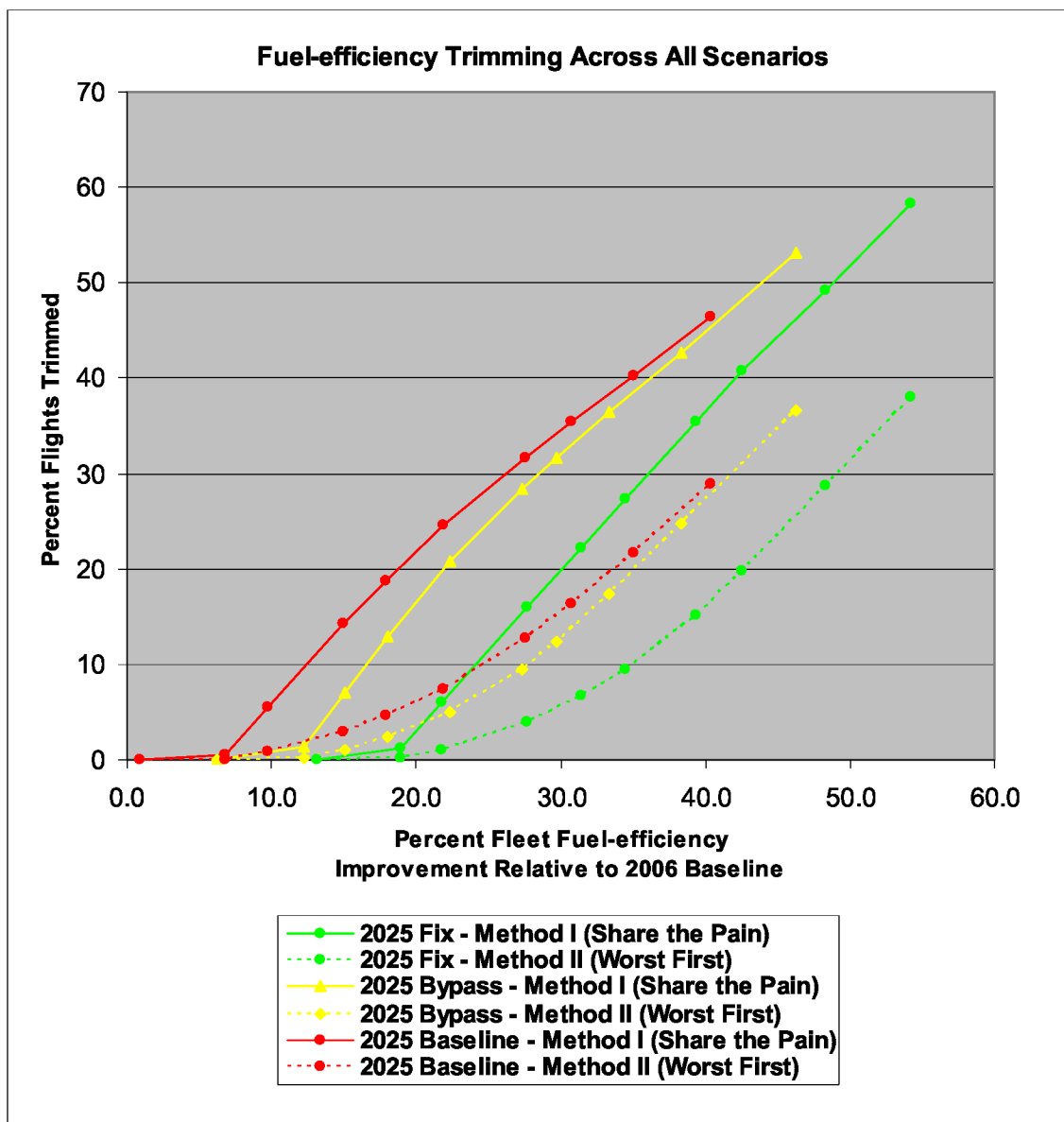


Figure 14.3 – Percentage of Flights Trimmed As a Function of Total Fleet Fuel-efficiency Improvement Using Methods I and II

Number of Years	Annual Rate of 1%	Annual Rate of 2%	Annual Rate of 3%
5	0.05	0.10	0.14
10	0.10	0.18	0.26
15	0.14	0.26	0.37
20	0.18	0.33	0.46
25	0.22	0.40	0.53
30	0.26	0.45	0.60

Table 14.4– Total Improvement Percentages for Several Annual Rates of Improvement

We also investigated the distribution of trimmed flights across seat classes for both trimming methods. The results of this analysis are shown in Figure 14.4 below. For each of the three 2025 scenarios, the charts show the number of flights trimmed under Methods I and II at approximately the same level of total improvement in the fleet fuel efficiency. Ten seat classes were addressed, with seating ranges given in Table 14.5.

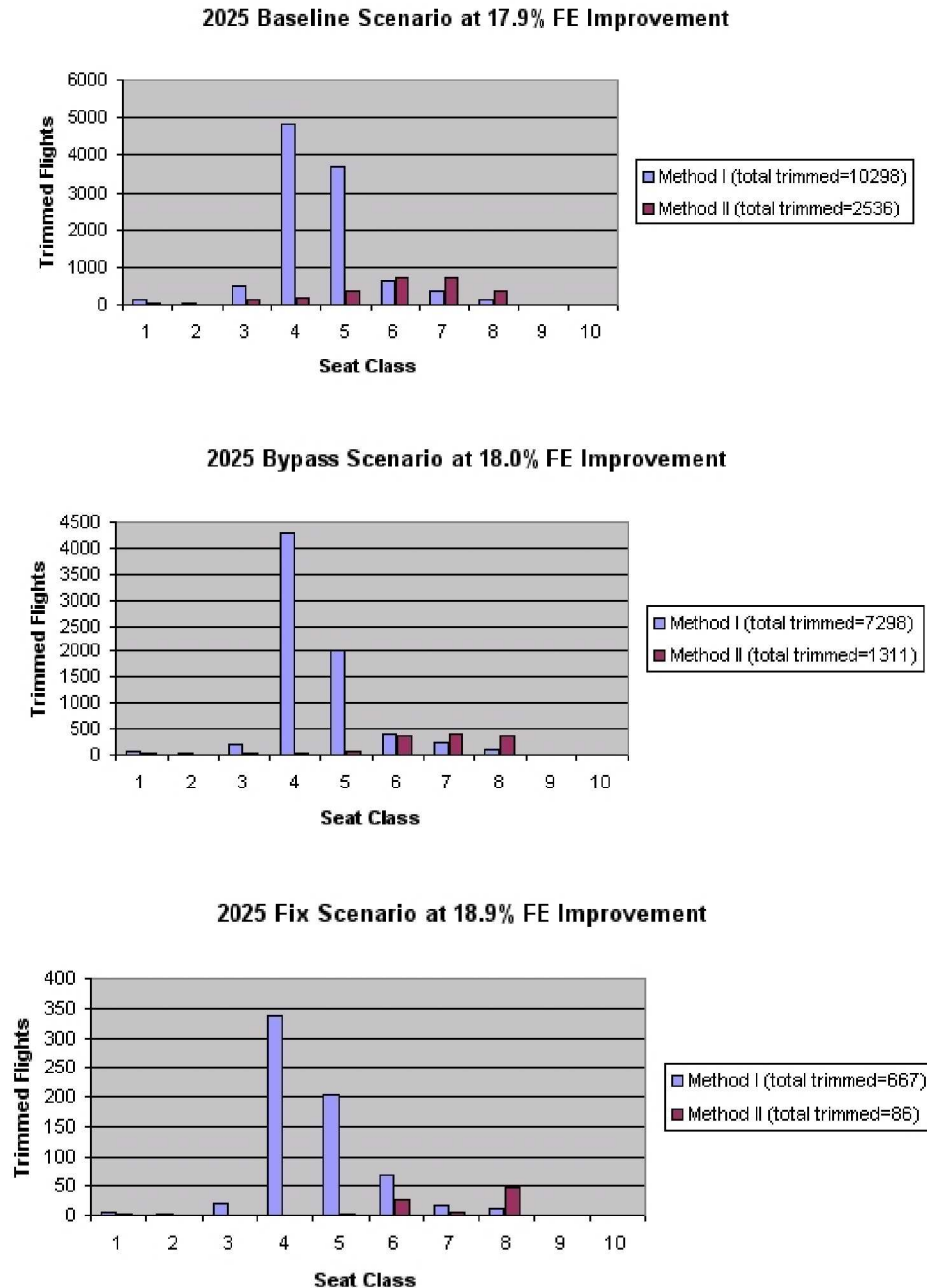


Figure 14. 4– Numbers of Flights Trimmed By Seat Class Using Methods I and II for Each Scenario

Seat Class	Number of Seats
1	<20
2	20-49
3	50-99
4	100-150
5	151-210
6	211-300
7	310-400
8	401-500
9	501-600
10	>=601

Table 14. 5 – Seat Classes and Numbers of Seats

Principal conclusions from the fuel-only trimming in these scenarios are as follows:

1. Method II (“Worst First”) trims fewer flights than Method I (“Share the Pain”) for any level of total fuel-efficiency improvement.
2. Method II shifts the trimming burden to larger aircraft, since they consume more fuel per unit distance traveled, the only factors considered in this formulation of the fuel-efficiency metric.
3. The performance characteristics of the 2025 Fix fleet make the differences in percentages of flights trimmed in Methods I and II small (approximately 1.2 and 0.2%, respectively) at the 18% level of total improvement (1% per year for 20 years). However, at higher levels of improvement, Method II trims significantly smaller percentage of flights. For example, at the 33% level of total improvement (2%/yr for 20 years), Method I trims about 28%, while Method II trims about 10% in the 2025 Fix scenario.

2.3.Combined Noise and Fuel Trimming

Finally a method of integrating the results of both noise and fuel trimming are combined to provide a common environmental constraint. If noise and fuel trimming affect exactly the same population of flights, then, after noise and fuel-efficiency trimming have been applied, we have produced a list of all flights processed, with each flight falling into one of the following categories:

- Flights affected by the noise goal alone;
- Flights affected by the fuel-efficiency goal alone;
- Flights affected by both goals; and
- Flights affected by neither goal.

In this list, each flight will have two numbers associated with it: a noise scaling and a fuel-efficiency scaling. If either of these numbers is 1.0, then the flight was not affected by the goal associated with that number. Once the flight populations are aligned, we can combine the noise and fuel-efficiency trimming as follows:

- For each flight, select the lower of the noise or fuel-efficiency scaling numbers (that is, the one that requires more trimming), and calculate the total flights remaining after trimming by summing across all flights using this value.
- The fraction of flights remaining is this number divided by the original number of flights (equivalent to the average of the resulting flight-specific scaling factors).

Scenario	Flights Processed	Relative to Baseline		Flights Remaining			Flights Trimmed	
2006 Baseline	37886	N/A		N/A	N/A		N/A	N/A
2025 Baseline	54777	1.4		22667	41%		32110	59%
2025 Bypass	56376	1.5		33056	58%		23320	42%
2025 Fix	54817	1.4		37838	69%		16979	31%

Table 14. 6 Combined Noise and Fuel Trimming Results

Note: Due to the fuel-efficiency Q/A step reducing the flight population by about 3%, the number of OEP-34 flights treated for noise trimming alone is somewhat higher than the number treated in combined noise and fuel-efficiency trimming. This does not affect the current results significantly.

3. Possible Next Steps

- Consider a wider range of trimming metrics for both noise and fuel.
- Identify surrogates that can be computed more quickly when attempting to trim flights.
- Create methods for flight level trimming for noise.
- Develop a trimming metric for emissions that is consistent with those pollutants of most concern.
- Evaluate methods for trimming locally rather than nationally.

15.0 Summary and Next Steps

Some highlights from this round of JPDO SMAD environmental analysis display improvements to the methodology and potential next steps to consider for future rounds of modeling. Additionally we continue to struggle to meet NextGen goals to reduce impacts to the environment although improvements to the system and aircraft do show overall benefits.

The most significant improvement to the methodology for this phase of analysis is the introduction of mixed fidelity modeling. By using an appropriate level of fidelity at

individual airports, the scope of the study has been increased and also still seems to be of sufficient sensitivity to capture appropriate environmental concerns. Two potential benefits include:

- Reduction in data analysis required to develop modeling inputs for both noise and emissions calculations.
- Reduced runtimes which would allow for a wider variety of scenarios to be considered.

As stated above, the results continue to suggest that traffic growth will outpace benefits from operational improvements as well as projected technology improvements to aircraft. The near term opportunities will focus primarily on operational improvement while the most significant component to reducing environmental impact is still the aircraft, specifically engine and airframe improvements. For each step in the methodology a section offering improvements was provided. Below is a snapshot of those that could provide added benefit to the approach and better understanding of the results.

- 1) A review of top level metrics with their associated goals and targets.
- 2) Integration of the payload based fuel metric.
- 3) Integration with alternative simulation models to provide quicker analysis and results.
- 4) Include forecasted population around metropolitan areas of interest.
- 5) Improve the fleet evolution process:
 - a. to consider itineraries
 - b. to better handle cargo and international flights
 - c. to account for “market driven” improvements to the fleet
- 6) Improve use of operational improvements
 - a. account for less than 100% penetration of equipage to support RNP/CDA procedures
 - b. extend CDA to top of descent
- 7) Update airports that have brought new runway on line since the original input radar analysis.
- 8) Produce a quick time model to estimate noise impacts.

Finally, although quality assurance is performed on the results it is important to realize the significance of the results and therefore suggest that more should be done. Future efforts should provide a detail breakdown of each of the validation steps so that they can be included and expanded for future rounds of analysis.

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14. ABSTRACT This document provides a summary of the current methods developed by Metron Aviation for the estimate of environmental effects and constraints on the Next Generation Air Transportation System (NextGen). This body of work incorporates many of the key elements necessary to achieve such an estimate. Each section contains the background and motivation for the technical elements of the work, a description of the methods used, and possible next steps. The current methods described in this document were selected in an attempt to provide a good balance between accuracy and fairly rapid turn around times to best advance Joint Planning and Development Office (JPDO) System Modeling and Analysis Division (SMAD) objectives while also supporting the needs of the JPDO Environmental Working Group (EWG). In particular this document describes methods applied to support the High Density (HD) Case Study performed during the spring of 2008. A reference day (in 2006) is modeled to describe current system capabilities while the future demand is applied to multiple alternatives to analyze system performance. The major variables in the alternatives are operational/procedural capabilities for airport, terminal, and en route airspace along with projected improvements to airframe, engine and navigational equipment.					
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